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A DYNAMICALLY AND ELASTICALLY SCALED MODEL

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INFLATABLE PARAWING DEPLOYMENT STUDIES USING

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H. Neale Kelly* and James F. McNulty+

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The paper describes wind-tunnel deployment studies of a dynamically and elastically scaled model of an inflatable parawing. Model design criteria and details are presented in a companion paper by Mr. Raff of Goodyear Aerospace Corporation. The parawing was deployed from a capsule mounted with rotational freedom in the wind tunnel. A deployment sequence providing a smooth transition from packaged to stable gliding flight was developed from preliminary studies at low airspeeds. High-speed motion pictures, shroud-line loads and positions, and capsule position were obtained during complete deployments at airspeeds corresponding to those anticipated for the full-scale vehicle. The results indicate that satisfactory deployments can be made with transient loads held to reasonable levels.

INTRODUCTION

Deployment studies using a dynamically and elastically scaled model of an inflatable parawing suitable for the recovery of a large spacecraft have been conducted in the Langley Transonic Dynamics Tunnel. The threefold purpose of the investigation was to study operational problems of deployment, provide a preliminary evaluation of transient loads associated with deployments, and assess the value of wind-tunnel studies in this field. The present paper describes the deployment studies and illustrates the feasibility of obtaining early design information through the employment of a wind-tunnel program in which deployment sequences and the resulting transient loads can be evaluated under controlled conditions.

The design, scaling, construction, and degree of similitude obtained in the fabrication of the model used in the investigation are described in a companion paper by Mr. Bruce Raff of Goodyear Aerospace Corporation.

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APPARATUS AND TESTS

The Transonic Dynamics Tunnel in which the deployment studies were conducted is especially well suited for dynamic model testing. The large (16-foot square) test section of the tunnel is well lighted for high-speed photography and is equipped with large windows for close unobstructed viewing of the model. Although only a small portion of the ranges was used in the present investigation, the tunnel is capable of operating over wide ranges of speeds and densities using either air or Freon-12 as a testing medium. For the deployment investigation the model* was gimbal mounted as shown in figure 1 to a bar which spanned the test section of the tunnel.

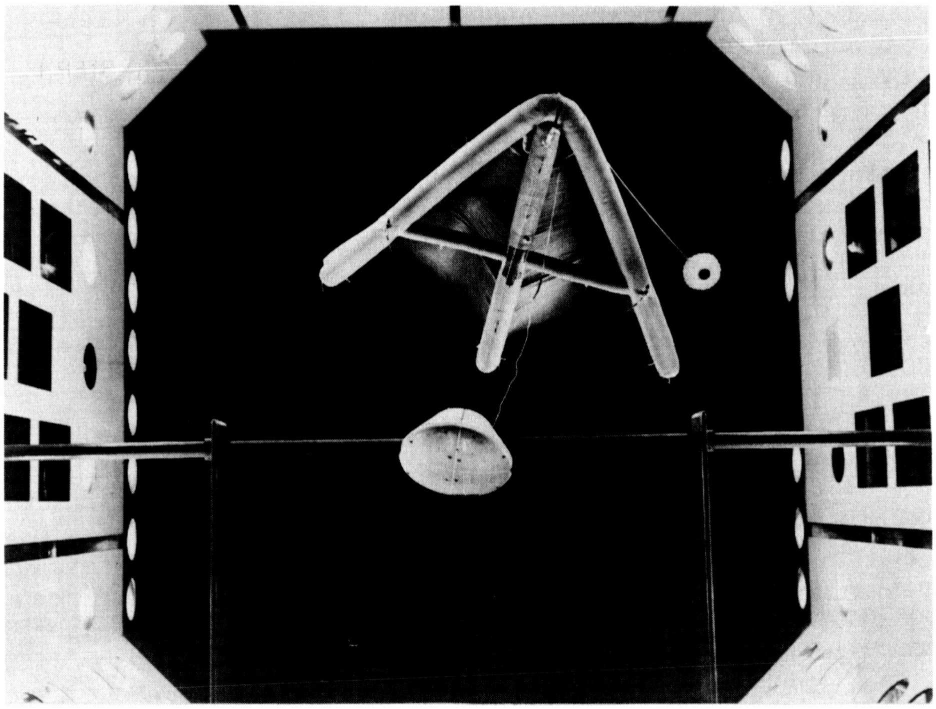

Figure 1.- Model mounted in tunnel.

The mount restrained the model in translation but the gimbal attachment, which consisted of a large self-alining ball bearing, allowed the model freedom in pitch and approximately 10° angular displacement in roll and yaw about the capsule center of gravity. Instrumentation incorporated within the capsule permitted continuous measurement of the capsule angular displacements and the shroud-line loads and positions during and following deployment. These measurements were recorded on multichannel oscillographs located in the tunnel control room. High-speed motion-picture cameras located upstream and abreast of the model on both sides of the test section recorded motions of the capsule and the parawing.

*The model was a 1/8-size dynamically and elastically scaled model of an inflatable parawing suitable for the recovery of an 8,800-pound spacecraft. A complete description of the model is given in the companion paper by Mr. Raff.

Deployment sequences investigated were of a "passive type," that is, required no powered reel in or out of the shroud lines as the model went from the packaged condition to the configuration for maximum gliding range. In general, the 4-step deployment sequence shown in figure 2 which is similar to that proposed by North American for the *Gemini* parawing was used.

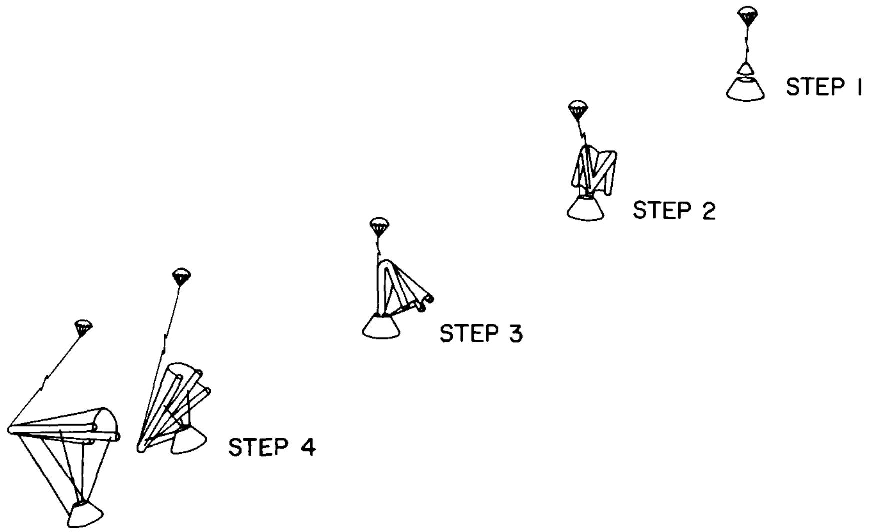

Figure 2.- Deployment sequence.

The four steps which were initiated remotely by squib-fired valves or line cutters were:

1. Jettison of aft heat shield and simultaneous deployment of drogue chute attached to parawing apex

2. Inflation of parawing

3. Release of aft end

4. Release of apex

Complete deployments were made at dynamic pressures simulating 1g, 2g, and 3g gliding flight. Partial deployments (steps 1 and 2) were made at dynamic pressures up to those simulating the terminal velocity of the capsule at an altitude of approximately 50,000 feet. Some of the preliminary studies were made at very low speed so that the investigators could enter the tunnel during the experiment.

PRELIMINARY STUDIES

Much useful qualitative information was obtained from visual observation and review of movies* of some of the preliminary tests in which various steps of the deployment (beginning with the 4 step and working back through the sequence) were attempted at low airspeeds.

Drogue Chute

Initial studies in which the parawing in the fully deployed condition was manually displaced to a high angle of attack and released indicated that the unrestrained parawing would pitch forward past the trim angles of attack to an angle at which the sail became unloaded, and then proceed to gyrate wildly as the sail alternately loaded and unloaded. A small drogue chute attached to the apex served to damp the forward motion of parawing sufficiently to avoid the overshoot and the consequent violent oscillations and high shock loads. It therefore appears that "Passive Type" deployments to the relative low angle of attack required for maximum range dictate the use of a drogue chute to avoid this highly undesirable condition. For deployments to higher angles of attack or for deployments in which the forward keel shroud line is slowly payed out the drogue chute may not be a necessity. In any event, the apex-attached drogue appears desirable in order to assure that the parawing assumes a stable flying attitude. Free-flight deployments made by the Flight Mechanics and Technology Division of the Langley Research Center using a controlled forward-keel shroud-line payout+ tend to confirm the need for the apex-attached drogue chute and indicate that the chute should not be jettisoned until transient motions generated by the deployment die out.

Transient Motions

It was noted in the preliminary tests and later confirmed by the records obtained during complete deployments that transient motions and loads associated with the various steps in the deployment decayed rapidly. Therefore with even a relatively short time interval between events, each step in the deployment acts as a separate entity with little or no interaction between steps. Furthermore, due to the short period of time required to accomplish each step, changes in altitude and velocity in each phase of an actual free-flight deployment should be small; hence, the study of parawing deployment in steps at constant dynamic pressures as in the present investigation appears justified.

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*An NASA film L-779 entitled "Paraglider Deployment in the Transonic Dynamics Tunnel" which depicts these preliminary tests and some of the complete deployments is available for loan from the Langley Research Center, NASA Langley Station, Hampton, Virginia.

+NASA Technical Note D-1932.

Controlled Reel Out

The early tests graphically illustrated the need for controlled reel out of the shroud lines, especially for the forward and aft keel cables. Even at the low airspeeds of the preliminary test, the 1/16-inch stainless-steel aircraft cables snapped under the combined inertial and aerodynamic loads as the shroud lines reached the end of their travel if the payout rate was not controlled. By restraining the payout rate through the use of the friction drag brake, incorporated in the reel assembly, the shock loads could be held to acceptable levels. Difficulty was encountered in presetting the drag brakes so that they provided sufficient restraint while still permitting the cable to pay out. Nevertheless, since replacement of the drag brakes with a different system required a major modification of the setup, the remainder of the tests were made using the friction drag brakes for shroud-line control.

DEPLOYMENT STUDIES

Partial Deployments (Steps 1 and 2)

Measurements were made of the loads in the fittings holding the apex and the aft ends of the parawing booms during cover release and inflation at dynamic pressures simulating the terminal velocity of the capsule at an altitude of approximately 50,000 feet. The maximum loads encountered during inflation at this dynamic pressure and steady-state loads at various dynamic pressures are presented in figure 3 in terms of load coefficient versus dynamic pressure.

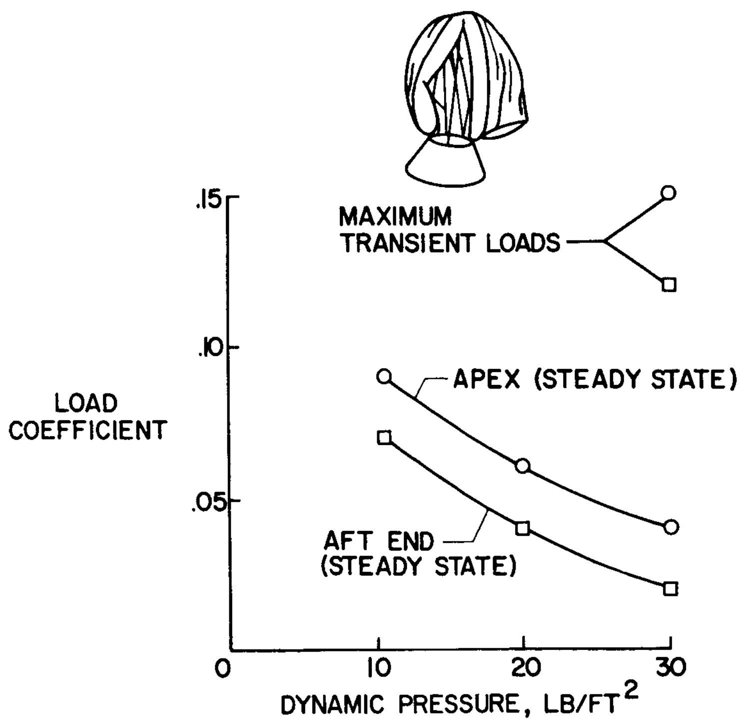

Figure 3.- Tie-down load coefficients.

It is evident from the figure that the transient loads during inflation may be as much as 3 to 4 times the steady-state loads at the same dynamic pressure. Also evident from the figure is the wide variation in the steady-state load coefficients with dynamic pressure. It is believed that this variation is the result of a change in shape of the drag body formed by the parawing in this configuration under aeroelastic loading. Fortunately, the variation is such as to relieve the load imposed by the parawing at the higher speeds.

For the data of figure 3 and in approximately half of the complete deployments the aft ends of the three booms were attached at a common point. In this configuration the parawing tended to rock back and forth about an axis passing through the apex and aft end attachment points. For some of the later tests the attachment points of the aft end of the leading-edge booms were displaced from the keel boom approximately 30° around the periphery of the top of the capsule. This configuration proved to be very stable and promoted a more rapid filling of the sail. Free-drop tests with a smaller, simplified model in a vertical wind tunnel confirmed the need for separate attachment points for the aft ends of the booms. In these tests the spread attachment configuration appeared very stable; whereas with the common point attachment, the capsule oscillated back and forth like a bell under the parawing.

Complete Deployments

Successful deployments were made at dynamic pressures simulating 1g gliding flight and at dynamic pressures 2 and 3 times that for 1g flight in order to obtain data which could be correlated with the dynamic pressure decay anticipated for the prototype. In every instance the maximum transient loads in the shroud lines were encountered during payout of the apex cable (step 4).

Maximum transient shroud-line load coefficients for deployments at conditions for 1g and 2g gliding flight using the 4-step deployment sequence and to 1g conditions for a deployment in which the apex and aft ends of the booms were released simultaneously (steps 3 and 4) are presented in figure 4.

An examination of the data of figure 4 reveals that the maximum ratio of transient shroud-line loads to steady-state loads was 3.0. With carefully controlled payout rates and sequencing, and with the load-relieving effects of body translational freedom* it is believed that the magnification factor can be reduced for the prototype.

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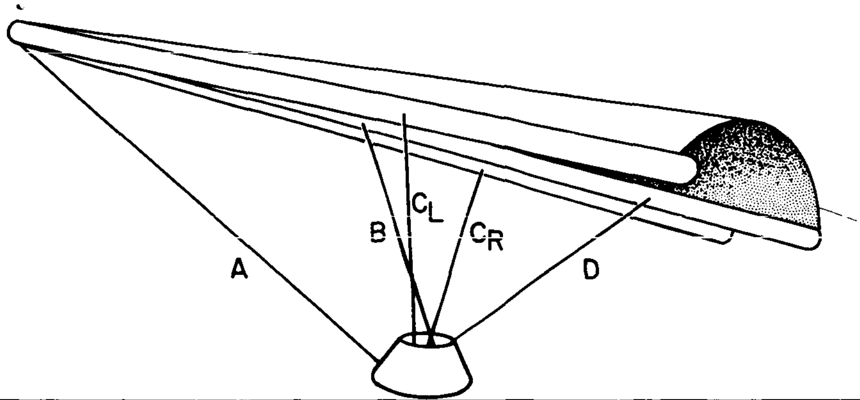
*While lack of translational freedom may cause discrepancies between tunnel and free-flight results, a theoretical analysis indicates that the discrepancy should not be beyond the accuracy required for engineering design; furthermore, design values will err on the conservative side.

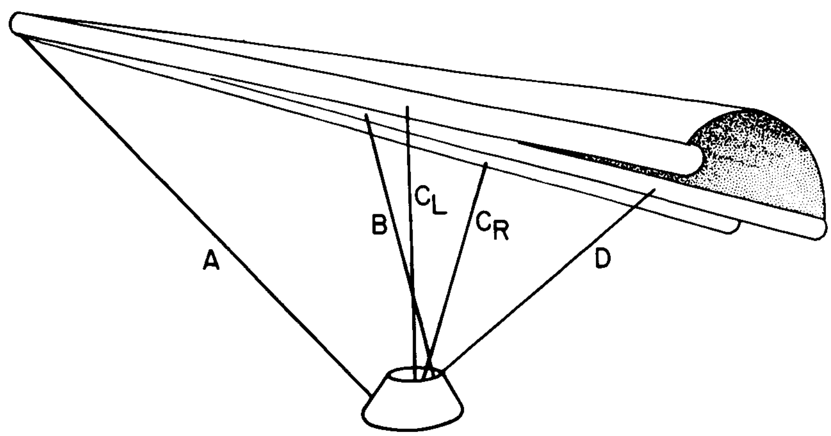


TYPE DEPLOYMENT	4-STEP				3-STEP	
DYNAMIC PRESSURE	3.5		7.0		3.5	
LINE	MAX	MAX / STEADY STATE	MAX	MAX / STEADY STATE	MAX	MAX / STEADY STATE
A	.26	1.6	.28	1.7	.32	2.1
B	---	---	---	---	.43	3.0
C_L	.34	1.1	.29	1.1	.41	1.4
C_R	.63	2.1	.33	1.2	.43	1.4
D	.59	1.8	.29	1.3	.47	2.0

Figure 4.- Deployment load coefficients.

Three other items of interest were noted during the deployment studies. These were (1) parawing with the aft ends of the booms released (step 3) was somewhat unstable and the sail was subjected to severe buffeting; the practical remedy for this condition was to minimize the time between steps 3 and 4 by initiating step 4 as soon as shroud lines had extended their full allowable length under step 3 tie-down conditions. (2) Rapid inflation did not cause excessive dynamic stresses in the parawing fabric; even with the booms buckled, full pressure could be put into the glider almost instantaneously without damage to the parawing. Again, in order to reduce buffeting of loose fabric, rapid passage through this phase appears advantageous. (3) Measurement of shroud-line loads and the capability of regulating dynamic pressure afforded the opportunity of checking the steady-state-stress analysis procedure. A comparison of measured and calculated shroud-line loads for 1g flight is given in figure 5.

It is seen that the measured shroud-line loads varied from the theoretical shroud-line loads by factors ranging from 0.9 to 1.5. Considering the sensitivity of loads to shroud-line length for this highly redundant structure, the agreement shown is felt to be a satisfactory check of analysis procedure. In addition, the model exhibited a tendency to buckle at the 2g loading which corresponds to the design criteria of buckle at 2g.



LINE	THEORY	EXPERIMENTAL	EXP/THEO
A	.18	.16	.89
B	.10	.15	1.50
C_L	.27	.28	1.04
C_R	.27	.31	1.15
D	.23	.32	1.39

Figure 5.- Steady-state load coefficients.

It should be noted that all deployments were not successful; in fact, approximately 50 percent were not successful due either to equipment deficiencies or faulty test technique. The model and capsule, however, survived the complete testing program of about 15 runs without requiring any major repairs. It is felt that, in this respect, tunnel testing has a big advantage over free-flight drops where a minor failure usually results in extensive damage to the model and instrumentation.

CONCLUDING REMARKS

The present investigation has indicated that much useful information both qualitative and quantitative can be obtained from deployment studies of an inflatable parawing in a wind tunnel. For example, the present studies revealed several important considerations that influence the development of a satisfactory deployment technique. The studies also indicate that parawings can be deployed with transient loads held to reasonable values. The use of wind tunnels as a tool in the study of deployment problems is indicated; however, final evaluation of the merits of the wind-tunnel studies awaits the results of comparable free-flight deployment studies.